CLAIMS

What is claimed is:

1. A quantum dot vertical cavity surface emitting semiconductor laser (VCSEL), comprising:

a first distributed bragg reflector (DBR) mirror disposed on a substrate layer comprised of a first plurality of mirror pairs with each mirror pair including layers having a step change in indices of refraction;

a second distributed bragg reflector (DBR) mirror comprised of a second plurality of mirror pairs with each mirror pair including layers having a step change in indices of refraction;

a semiconductor quantum dot active region disposed between a top of the first DBR mirror and a bottom of the second DBR mirror, the quantum dot active region including a plurality of quantum dots embedded in a plurality of quantum wells disposed proximate at least one antinode of a longitudinal optical mode, the quantum dots having a corresponding optical confinement factor;

first and second doped semiconductor intracavity contact layers each having a thickness of no more than about half a wavelength disposed between the first and second DBR mirrors positioned and doped to inject electron-hole pairs into the quantum dot active region in response to a drive current;

the mirror pairs of at least one of the DBR mirrors comprised of a semiconductor layer and an oxidizable semiconductor layer which has been oxidized to form a material with a refractive index substantially lower than the unoxidized semiconductor, increasing the reflectivity of the mirror; and

at least one mode control layer disposed between the top of the first DBR mirror and the bottom of the second DBR mirror forming a refractive index profile to increase optical confinement of the quantum dot active region and reduce optical confinement in the contact layers.

2. The VCSEL of claim 1, wherein the number of quantum dot layers, the optical confinement of the quantum dot layers, and an optical overlap in doped contact layers is selected to achieve a threshold gain that is less than a saturated gain of a ground state of the quantum dots over a temperature range between about 0 °C to about 85 °C.

3. The VCSEL of claim 2, wherein the active region has a longitudinal thickness that is about an integer number of half wavelengths in the laser at a target emission wavelength.

4. The VCSEL of claim 1, wherein each mode control layer has a longitudinal thickness of about one quarter of the emission wavelength in the laser, has a refractive index different that adjacent layers, and is positioned in the cavity to form a resonant reflection acting to increase the longitudinal mode

intensity in the quantum dot active region and decrease the longitudinal mode intensity in the contact layers.

5. The VCSEL of claim 4, wherein there is a first mode control layer disposed between a first end of the active region and the first mirror and a second mode control layer disposed between a second end of the active region and the second mirror.

6. The VCSEL of claim 5, wherein each mode control layer is disposed between an end of the active region and a heavily doped contact layer.

7. The VCSEL of claim 1, wherein the second DBR mirror comprises mirror pairs having an oxide layer and a semiconductor layer.

8. The VCSEL of claim 7, wherein the first DBR mirror comprises mirror pairs having a semiconductor layer and an oxidizable semiconductor layer with at least one opening is formed in the first DBR mirror through the oxidizable semiconductor layer to laterally oxidize the oxidizable layers with a laterally connecting portion of the first DBR mirror along at least one side of the first DBR mirror to inhibit delamination of the first DBR mirror.

9. The VCSEL of claim 1, wherein the at least one DBR mirror comprised of a semiconductor layer and an oxidizable semiconductor layer further comprises: an intermediate layer disposed between the semiconductor

layer and the unoxidizable semiconductor layer having a composition selected to inhibit delamination of the oxidized DBR mirror.

10. The VCSEL of claim 8, wherein the substrate is a GaAs substrate and the quantum dots comprise self-assembled InAs quantum dots formed in InGaAs quantum wells, and the DBR mirrors layers comprise alternating layers of $Al_xGa_{1-x}As$ and $Al_yGa_{1-y}As$, where x is greater than y.

11. The VCSEL of claim 10, wherein the Al molar fraction of the $Al_xGa_{1-x}As$ layer is selected to be between about 0.95 to 0.99 whereby the oxidation rate of the $Al_xGa_{1-x}As$ layer is controlled.

12. The VCSEL of claim 1, wherein there is a first mode control layer is disposed between a first end of the active region and the first mirror and a second mode control layer disposed between a second end of the active region and the second mirror, each mode control layer having a longitudinal thickness of about one quarter of the emission wavelength in the laser, has a refractive index different than adjacent layers, and is positioned to form a resonant reflection acting to increase the longitudinal mode intensity in the quantum dot active region and decrease the longitudinal mode intensity in the contact layers.

13. The VCSEL of claim 12, wherein each mode control layer has a refractive index lower than adjacent layers.

14. The VCSEL of claim 13, wherein the active region has a thickness that is approximately an integral number of half wavelengths in the laser.

15. The VCSEL of claim 12,wherein each mode control layer has a refractive index higher than adjacent layers.

16. The VCSEL of claim 15, wherein the active region has a thickness that is approximately an odd number of quarter wavelengths.

17. A vertical cavity surface emitting semiconductor laser (VCSEL), comprising:

a first distributed bragg reflector (DBR) mirror;

a second distributed bragg reflector (DBR) mirror spaced apart from the first mirror to form a microcavity for a longitudinal optical mode;

a semiconductor quantum dot active region having a first end and a second end disposed in the microcavity between the mirrors;

first and second doped semiconductor intracavity contact layers disposed in the microcavity on opposed ends of the quantum dot active region doped to inject electron-hole pairs into the quantum dot active region in response to a drive current;

at least one mode control layer disposed in the microcavity;

the at least one mode control layer having a refractive index profile for generating reflections within the microcavity which create a resonance condition

that increases optical confinement in the active region and decreases optical loss in contact layers.

18. The laser of claim 17, wherein each mode control layer is approximately a quarter of a wavelength in thickness and has a refractive index profile different than adjacent layers.

19. The laser of claim 18, wherein each mode control layer is disposed between the active region and a heavily doped portion of a contact layer.

20. The laser of claim 17, wherein at least one of the DBR mirrors is an ultrahigh reflectivity DBR mirror formed by laterally oxidizing DBR mirror pair layers that include an oxidizable semiconductor layer and a substantially non-oxidizable semiconductor layer.

21. The laser of claim 20, further comprising an intermediate composition layer disposed between the oxidizable semiconductor layer and the substantially non-oxidizable semiconductor layer to inhibit delamination.

22. The laser of claim 20, wherein the first mirror is formed into a mesa laterally oxidized along at least one side; and

the second mirror has its bottom surface disposed on a substrate layer, the second mirror having at least one cavity disposed through it through which the second mirror is oxidized and at least one connecting section providing lateral support.

23. The laser of claim 21 wherein the laser has a threshold gain less than a saturated gain of a ground state of the quantum dots in a temperature range between about 0 °C and 85 °C.

24. A vertical cavity surface emitting laser, comprising:

first and second distributed bragg reflector (DBR) mirror means for forming an optical cavity between the mirror means having optical feedback;

quantum dot active means disposed within the optical cavity for providing optical gain responsive to a current;

intracavity contact layer means for proving current to the quantum dot active means; and

resonant mode control layer means disposed between the mirror means for increasing the optical confinement of the quantum dot active means and reducing the optical intensity in the contact layer means.

25. The laser of claim 24, further comprising:

delamination inhibition means for inhibiting the delamination of the high reflectivity mirror means.

26. The laser of claim 24, wherein a threshold gain of the laser is less than a saturated ground state gain over a temperature range between about 0°C to 85°C.

27. A method of forming a vertical cavity surface emitting laser having an oxidized bottom distributed bragg reflector (DBR) mirror with lateral support, comprising:

etching at least one opening into mirror layers of the bottom DBR mirror, the at least one cavity disposed proximate an outer perimeter of a lasing portion of the bottom DBR mirror with at least one lateral connecting portion of the mirror layers remaining to support the lasing portion of the mirrors; and

laterally oxidizing the mirror layers of the bottom DBR mirror.

28. The method of claim 27, wherein the bottom DBR mirror includes AlGaAs layers and the mirror layers are oxidized in steam.

29. The method of claim 28, wherein the mirror layers comprise AlAs/GaAs layers laterally oxidized to AlO/GaAs.

30. The method of claim 29, further comprising an intermediate composition layer disposed between the AlAs and GaAs layer.

31. The method of claim 30, wherein the AlAs layer comprises a molar fraction of gallium of at least about 0.01 for improved control of lateral oxidation rates.

32. A vertical cavity surface emitting laser fabricated by the method of claim 27.

33. A method of forming a vertical cavity surface emitting laser with intracavity contacts from a substrate having a top DBR mirror with DBR mirror layers, a bottom DBR mirror with DBR mirror layers, a top contact layer, an active region, and a bottom contact disposed between the mirrors, the method comprising:

etching a top mirror mesa to expose the top contact layer outside of a top mirror for the VCSEL;

masking the top mirror mesa and etching down to the bottom contact layer;

etching at least one opening into mirror layers of the bottom DBR mirror, the at least one opening disposed proximate an outer perimeter of a lasing portion of the bottom DBR mirror with at least one lateral connecting portion of the layers remaining to support the lasting portion of the mirrors; and

laterally oxidizing the mirror layers of the bottom DBR mirror through the at least one opening.

34. The method of claim 33, further comprising: depositing a top contact metallization on a portion of the top contact forming a metal contact on the top contact layer about the top mirror mesa leading to a contact pad prior to etching down to the top contact layer.

35. The method of claim 33, further comprising: depositing a bottom contact metallization on a portion of the exposed bottom contact layer prior to etching through the bottom mirror layers.

36. The method of claim 33, wherein the bottom DBR mirror layers include AlGaAs layers with an aluminum molar fraction greater than 0.90 and the AlGaAs layers are laterally oxidized in steam.

37. The method of claim 36, wherein the bottom DBR mirror layers are oxidized at a temperature of less than 450 °C.

38. A vertical cavity surface emitting lasers fabricated by the process of claim 33.

39. A vertical cavity surface emitting lasers fabricated by the process of claim 36.